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(54) Abstract Title

Minimising interference in a cellular mobile telecommunications system

(57) Described herein is a method of minimising the received signal to noise plus interference ratio for a mobile telecommunications system comprising a plurality of cells, each cell having a base station and a plurality of mobile stations associated therewith. The method comprises measuring the inter cell and intra cell interference, determining a weighted sum of the measured inter cell and intra cell interference, and using the weighted sum as a basis for automatic transmit power control. The automatic transmit power control can be implemented as either open loop or closed loop power control.

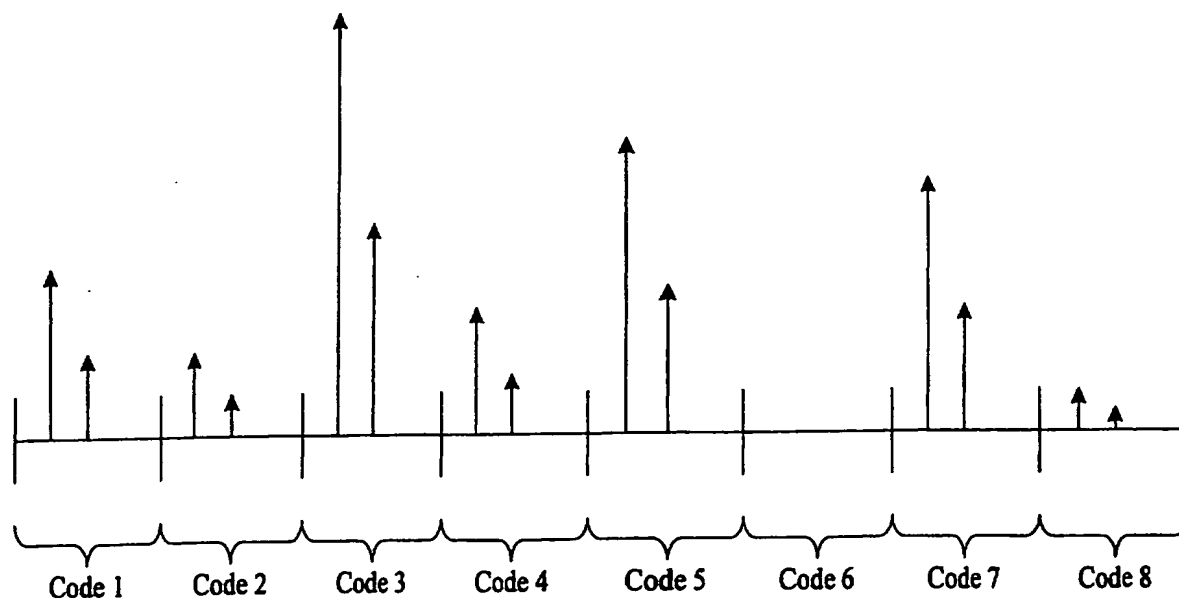


Fig. 1

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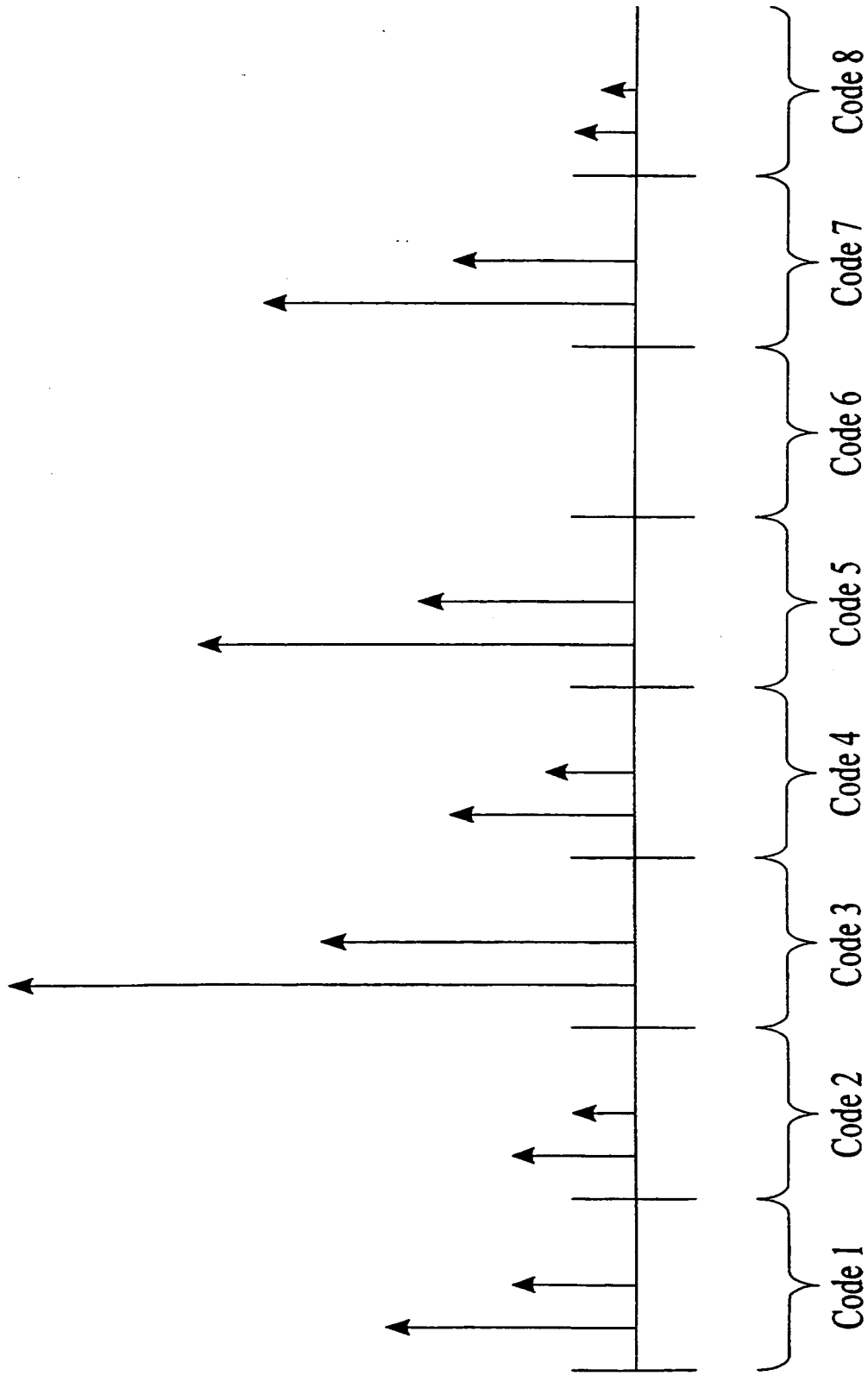


Fig. 1

IMPROVEMENTS IN OR RELATING TO MOBILE TELECOMMUNICATIONS SYSTEMS

The present invention relates to improvements in or relating to mobile
5 telecommunications systems.

The UMTS terrestrial radio access (UTRA) – time division duplex
(TDD) system is based on a combination of code division multiple access
(CDMA) and hybrid time division multiple access (TDMA) and TDD.
(UMTS is an acronym for universal mobile telecommunication system as
10 understood by persons skilled in the art.)

Within any given time slot, several CDMA codes can be transmitted
contemporaneously on the same frequency. These codes may be transmitted
to/from one mobile station or to/from several mobile stations or any
combination thereof.

15 The signals in a given time slot are transmitted using orthogonal
codes. However, multi-path in both directions and lack of complete
synchronisation on the uplink (that is, from mobile station to base station)
mean that the signals are modified in such a way that they are not orthogonal
on receipt. In order to mitigate this effect, the receivers in UTRA TDD
20 utilise a joint detection process which treats the sum of all signals on their
various codes as a composite signal which is equalised. This has the effect of
allowing demodulation of the signals as though they were orthogonal. This
process is extremely effective and significantly mitigates the so-called ‘near-
far’ problem of CDMA systems in which receipt of an interfering signal at
25 significantly higher power than a wanted signal can make successful
demodulation of the wanted signal impossible in spite of the processing gain.

The joint detection process is not perfect, however. Imperfections
arise for various reasons including limited precision of quantization in the

analogue to digital conversion in the receiver and imperfections in the channel estimates which are obtained in a way described later.

Within the TDMA/TDD structure of UTRA TDD, the transmission in each time slot consists of a signal 'burst' which comprises three components, namely, a first data field, a midamble field containing a midamble code which serves to provide a training sequence, and a second data field.

As mentioned earlier, UTRA TDD also contains a CDMA component wherein several spread spectrum modulated signals can be made contemporaneously in any given time slot. Thus, for example, eight signals, each using a different spreading code may be transmitted in a given time slot. Each signal will consist of its own unique data fields and midamble code. Thus, the first data fields for each signal are transmitted contemporaneously followed by the midamble codes for each signal (each midamble code being different), followed by the second data fields.

In the downlink direction, all signals are added together before being transmitted from the base station site. In the uplink direction, one or more mobile stations may each transmit one or more signals in a given time slot.

UTRA TDD uses a highly optimised structure for the midamble codes. This structure has been arranged to allow a channel estimate to be obtained from a given midamble code in such a way that interference from other midamble codes transmitted in the same time slot is substantially eliminated. The details of this approach are obtained in "Optimum and Sub-optimum Channel Estimation for the Uplink of CDMA Mobile Radio Systems with Joint Detection" by Bernd Steiner and Peter Jung, ETT, Vol. 5, No. 1, Jan-Feb 1994, pages 39-50. Note that although the title refers only to the uplink, the techniques described in the paper are also useful, and applicable, to the downlink of UTRA TDD.

To summarise the principles detailed in the paper, for a given base station, the same base code is used for all midamble codes. The different midamble codes for the different signal transmissions are obtained as cyclic shifts of an extension to the base code.

5 In a conventional receiver, a channel estimate would be formed from the midamble code by correlating against the code thereof. However, if this is done, there will be substantial interference from the other midamble codes in other signals due to their non-ideal cross-correlation properties. In the approach described in the reference, a cyclic correlation is performed against
10 the midamble code. The reference for the cyclic correlation is the 'inverse' of the midamble base code.

This 'inverse' can be obtained either by forming the inverse of a Toeplitz matrix formed from the base code and reversing the order of the first row or by forming the discrete Fourier transform of the base code, taking the
15 reciprocal of each value and then performing the inverse discrete Fourier transform and reversing the order. Correlation against the reverse of a waveform is equivalent to convolution. Convolution of a code with its inverse essentially creates an impulse.

The base code(s) is(are) selected by computer search to have a
20 reasonably flat spectrum and, in particular, to avoid deep troughs in the magnitude which would lead to peaks in the inverse spectrum.

The shifts in the base code which provide the midamble codes are selected to exceed the maximum delay spread plus delay uncertainties for the anticipated radio channel. Thus, the output of the cyclic correlators will be a
25 set of impulse responses for each of the signals, separated by the shifts.

On the downlink, the path is the same for all midamble codes. However, it is still appropriate to transmit multiple midamble codes in order to provide information concerning the power transmitted on each signal in

the time slot. This will apply if the same power is used for the midamble code as for the data fields for each signal.

As UTRA TDD operates in a cellular re-use structure, it is therefore desirable to minimise the transmit power, subject to the requirement to
5 provide acceptable service quality, at all times in order also to minimise inter cell interference.

It is therefore an object of the present invention to provide a method of setting the received signal to noise and interference ratio (SNIR) to the minimum necessary to provide acceptable service quality.

10 In accordance with one aspect of the present invention, there is provided a method of minimising interference in the presence of one or more simultaneous co-channel intra cell signals in a mobile telecommunications system comprising a plurality of cells, each cell having a base station and a plurality of mobile stations associated therewith, the method comprising the
15 steps of, in one or more cells and one or more base stations or mobile stations:-

- measuring inter cell interference;
- measuring intra cell interference;
- determining a weighted sum of the measured inter cell and intra cell
20 interference; and
- using the weighted sum as a basis for automatic transmit power control.

Automatic transmit power control (ATPC) is therefore employed to attempt to keep the received signal to noise and interference ratio (SNIR) to
25 the minimum necessary for successful communications. ATPC can be implemented either as closed loop or open loop power control.

For a better understanding of the present invention, reference will now be made, by way of example only, to the accompanying drawing, the single Figure of which illustrates a set of channel estimates.

The present invention primarily concerns closed loop power control for ATPC, although it may also have some application to open loop power control.

The basic principle of closed loop power control is that a receiver measures the SNIR of the signal of interest and compares this against a threshold corresponding to the desired SNIR. This comparison generates a binary signal which indicates whether the transmit power should be increased or decreased in order for the actual SNIR more closely to match the desired SNIR. This binary signal is modulated onto the transmitter at the site of the SNIR measurement and signals back to the source of the signal whose SNIR is being measured. This source demodulates the binary signal and uses it to adjust its transmit power in accordance with the requirement.

In a telecommunications cell comprising a base station and at least one mobile station, consider the downlink, that is, the base station to mobile station link, in which at least one mobile station receiving a signal on a code in a particular time slot is located close to the base station and at least one mobile station receiving a signal on a code in the same time slot is located far away from the base station. If SNIR measurements are performed on the basis of closed loop ATPC and if the interference part of the measurement excludes intra cell interference, then the difference in power between the transmissions from the base station to the mobile station in the two categories could be considerable, for example, 40dB.

However, as already mentioned, the difference in power at which joint detection can operate is limited due to practical considerations. A typical figure for this maximum difference is around 20dB.

If, on the other hand, SNIR measurements are performed in such a way that the interference part of the measurement includes the intra cell interference, then there will be very little difference in power between the downlink signals and much of the benefit of joint detection will have been wasted.

A downlink set of channel estimates is illustrated in Figure 1. Note, that all impulse responses are scaled replicas. Note, also that no signal is being transmitted in the sixth position. In Figure 1, the positions with no arrows are indicative of the inter cell interference. Similarly, the positions with arrows are indicative of the intra cell interference except where the wanted signal is.

Inter cell interference can be measured in any of the ways described in co-pending British application no. _____ (Ref: 1999P04838), and intra cell interference can be determined using the midamble codes.

For the downlink in a telecommunications cell comprising a base station and at least one mobile station, a Broadcast Control Channel (BCCH) is transmitted in one time slot in every frame from every base station. Because of its broadcast nature, this signal must be transmitted with enough power to reach every location in the cell. Thus, automatic transmit power control is not applied to this signal. Every mobile station affiliated to a given base station should be able to receive its BCCH and the associated midamble code should be strong.

Thus, the channel estimate window associated with the BCCH should be an effective means of identifying the signal path positions. This can be done by applying a threshold to the measurements. The threshold can be determined in one of two methods.

In one method, if the measurement window is wider than the anticipated delay spread, then the margin can be used for measurements of

inter cell interference plus receiver noise. If this margin is large enough to provide a large enough number of measurements, then no further action need be taken. However, on the other hand, if the margin is not sufficiently large, then the relatively poor estimate of inter cell interference plus receiver noise
5 obtained from the measurements in the margin can be used to set the threshold level. The threshold level will be set at some suitable multiple of the measured inter cell interference plus noise. The other measurements are then compared against the threshold level and those which exceed the threshold level are designated as containing signal components.

10 Note that the whole process can be made more effective in terms of fewer misdirected signal components and fewer falsely detected noise only components by averaging the measurements over several frames.

15 An alternative method requires identifying the signal components which are applicable when there is no 'margin'. This method comprises the steps of:-

i) Ranking the measured energies in descending order of magnitude and selecting the N strongest energies as containing the signal components. A suitable value for N would be in the range 3 to 12, for example.

20 However, if there are fewer than N actual signal components, then noise only components will be falsely designated as containing signal components. This can be overcome by performing a two-stage process in which the first stage is to determine a threshold level against which the signal energies are compared to identify the signal components as described above,
25 and the second stage is to rank the measured energies in descending order of magnitude.

ii) Forming a measurement of the inter cell interference plus receiver noise using the positions in which signal components were not

found. This measurement can then be used to set a threshold level in the same way as described earlier to identify the signal components.

Once the refined list of signal components has been obtained, it can be used to obtain a refined estimate of the inter cell interference from
5 measurements in the positions when signal components were not found. As for the previous method, the process can be made more effective by averaging the measurements over multiple frames.

In the methods described so far, the signal components are identified at specific locations. In practice, it must be appreciated that the signals are
10 filtered and then sampled once per chip. If the sampling takes place at the peaks of the filter response, then there will be nominally zero response in positions other than the peak response position to a particular multipath component. This is true because the combination of the transmitter and receiver filter responses is typically selected to provide an overall Nyquist
15 response.

If, however, the sampling is at any other position there will be responses at non zero levels in the surrounding positions. For example, if the sampling is exactly halfway between the peak response positions, there will be two equal amplitude responses accompanied by additional responses
20 symmetrically disposed about the centre responses. If the transmit and receiver filter responses are both square root raised cosine in the frequency domain with excess bandwidth factor of 0.22 as specified for UTRA TDD, then the magnitude of these responses relative to the centre responses will be:-

| No. | Level (dB) |
|-----|------------|
| 1 | -10.8 |
| 2 | -18.1 |
| 3 | -26.4 |
| 4 | -41.2 |
| 5 | -40.9 |
| 6 | -37.6 |
| 7 | -39.9 |
| 8 | -47.5 |
| 9 | -59.8 |
| 10 | -47.8 |

It is possible that responses detected above the threshold level may have associated responses which are below the threshold. This problem can
5 be overcome by setting a window around the detected responses in which inter cell plus receiver noise measurements will not be made. This can be done either in the form of a fixed width window, for the sake of simplicity, or an amplitude dependent window.

In the case of the amplitude dependent window, the approximate ratio
10 of the signal response to the inter cell interference plus receiver noise is measured. Then, any positions for which worst case sampling could lead to responses more than, say, 10dB below the level of the inter cell interference plus receiver noise, would be excluded from the measurements.

A further refinement would be to look for adjacent pairs of peak
15 responses. Depending on the relative amplitudes, the approximate levels of related responses could be predicted.

It has been assumed that the positions of the signal multipath components are identified by measurements of the midamble code associated with the BCCH in the BCCH time slot. It will, however, be appreciated that
20 the levels of received signal power and inter cell interference plus receiver noise will vary from time slot to time slot. Because the BCCH is a broadcast

transmission, it should be transmitted at the maximum power. Thus, from the viewpoint of absolute signal power, the window set for the positions of signal components based on BCCH measurements should also be appropriate for other time slots. However, if the inter cell interference is lower in other time slots then the effect of signal presence in terms of corrupting the measurements will be more severe. In this case two options are available, either:-

- a) To identify the paths in the relevant time slot; or
- b) To use the BCCH time slot with a conservatively specified fixed window.

It should be appreciated that although the method of the present invention has been described with reference to the use of measurements in the BCCH time slot and midamble code for identifying signal path position, the present invention is equally applicable to measurements on other codes and/or in other time slots.

Once the available positions for measurement of inter cell interference plus receiver noise have been identified, such measurements may be performed in any of the time slots in a cell of a base station which are either inactive and assigned to downlink operation, or currently unassigned to that base station. Not all of the measurement positions need to be used. Computational complexity can be reduced at the expense of increased measurement variance by taking fewer measurement samples. Moreover, it is not necessary to perform measurements in every time slot in every frame.

Furthermore, where the mobile station can determine that a particular code in a given time slot is not in use, all of the correlator positions across the measurement window for the code are available. When measuring inter cell interference plus receiver noise in time slots which have not been assigned to a mobile station's affiliated base station, measurements can be performed

without correlating against the inverse of the base station's code since there is no intra cell interference to be eliminated in this case.

As mentioned earlier, further improvements to the DCA scheme can be obtained by having the mobile station correlate using the inverse
5 midamble codes of its neighbouring base stations. This can be used in two different ways.

One way is to measure the signal energy in the neighbouring cell's BCCH. This would give a measure of the path loss to the neighbouring base station, given knowledge of that base station's transmitted power on its
10 BCCH signal. When the mobile station signals this information back to the network, the latter can then predict the level of interference from that neighbouring base station at the mobile station given knowledge of the neighbouring base station's transmit power in all of its downlink slots on all assigned codes.

15 An alternative way is to arrange for the mobile station to measure inter cell interference plus receiver noise using any of the techniques previously described except that the inverse midamble code is that of the neighbouring cell. In this case, the mobile station is measuring inter cell interference as though it were affiliated to the neighbouring cell. Thus, the
20 measured inter cell interference is different from that measured in the normal case in that it does not contain the component due to the neighbouring base station but does contain what would normally be considered as intra cell interference. In this case, the measurements in the two cases can be subtracted to provide the difference between the intra cell signal power and
25 the inter cell interference component from the selected neighbouring cell. Since the intra cell signal power can readily be measured, it then becomes possible to compute the component of inter cell interference from the selected neighbouring cells.

If the above procedure is performed for multiple midamble codes corresponding to the significant neighbouring base stations, then a complete characterisation of the radio paths involved in the system operation becomes possible.

5 Although the purpose of the present invention is to determine intra and inter cell interference in the primary paths, a by-product thereof is that a measure is provided of the inter cell plus receiver noise in positions not occupied by the primary paths.

10 It will be apparent that a considerable number of the locations across the cyclic correlator output contain no signal energy. If there were no receiver noise or inter cell interference, and ignoring any effect due to the receiver and transmitter filtering which tend to extend the responses to multipath, the level in the "no signal" positions would be equal to zero. This arises directly from the cyclic convolution against the inverse code.

15 Thus, measurement of the energy by forming the modulus squared in the no signal positions provides measurement of the receiver noise plus inter cell interference uncorrupted by the intra cell signals.

20 Thus, by dividing the sum of the power in the 'signal present' by the average of the power in the 'no signal' positions, we obtain a measure of SNIR. Because of the way that the measurements are performed, the interference component in the SNIR determination contains nominally no intra cell interference.

25 The intra cell interference level could be determined either by adding together the path powers for all the midamble codes (that is, for all of the midamble offsets) other than the midamble code corresponding to the wanted signal. Alternatively, the total received midamble code power could be measured by forming the modulus squared of the complex baseband samples over the period of the midamble code. By subtracting the measured intra cell

plus receiver noise and the wanted signal power with suitable pre-determined weightings, the intra cell received power can be determined.

The substance of this invention is to compute SNIR as the basis of ATPC by using a weighted sum of measured inter cell interference plus noise and intra cell interference. Typically, the inter cell interference plus noise is included with a weighting of unity and the intra cell interference with a weighting somewhere in the range 0.03 to 0.003. In computing the SNIR, the processing gain is, of course, taken into account.

Let us define the SNIRNICI as the SNIR computed on the basis of no intra cell interference. The effect of using an SNIR measurement computed in accordance with the present invention is to cause the true value of the SNIRNICI to increase as the intra cell interference increases. This operation tends towards the behaviour which simulations have indicated is ideal for joint detection operation.

Typically, the curves plotted for joint detection of bit error rate (BER) against received energy per bit to noise spectral density (E_b/N_o) ratio are shifted to the right as the level of intra cell interference increases. Thus, by including a small fraction of the intra cell interference measurement in the definition of the overall interference, the demanded E_b/N_o will increase in such a way as to tend to maintain the BER more constant as the intra cell interference increases.

As the relative levels of paths for the wanted and unwanted intra cell signals increase so that the path for the wanted signal is better, the power for the wanted signal can be reduced. However, the inclusion of intra cell interference in the computation of SNIR will limit the degree of reduction which can be taken.

This will cause the dynamic range of signals into the joint detection processor to be constrained to the optimum range.

It may also be desirable to incorporate a non-linear function into the combining of inter and intra cell interference measurements. This may enable the change of demanded E_b/N_0 as a function of intra cell interference level, more faithfully to match that shown by simulation to be required.

5 It has been assumed that the intra cell interference can be treated as a single quantity, this being the sum of the powers of the interfering intra cell signals. If non-linear weightings are incorporated, it may be advantageous to compute the total weighted intra cell interference as a non-linear and/or
10 unequally weighted sum of the powers of the individual intra cell interfering signals.

CLAIMS:

1. A method of minimising interference in the presence of one or more simultaneous co-channel intra cell signals in a mobile telecommunications system comprising a plurality of cells, each cell having a base station and a plurality of mobile stations associated therewith, the method comprising the steps of, in one or more cells and one or more base stations or mobile stations:-
 - a) measuring inter cell interference;
 - b) measuring intra cell interference;
 - c) determining a weighted sum of the measured inter cell and intra cell interference; and
 - d) using the weighted sum as a basis for automatic transmit power control.
2. A method according to claim 1, wherein step a) comprises (i) associating a channel estimate window with each of the one or more simultaneous co-channel intra cell signals which interfere with measurement of the inter cell interference; (ii) identifying signal path positions for each channel estimate window; (iii) determining those positions within the channel estimate window which have no signal components; and (iv) using measurements in the positions having no signal components to provide the estimate of inter cell interference.
3. A method according to claim 2, wherein step (ii) comprises applying a threshold to measurements in each channel estimate window.

4. A method according to claim 3, wherein the threshold is set at a multiple of measured inter cell interference plus noise.
5. A method according to claim 2, wherein step (ii) comprises measuring energies within the channel estimate window, ranking the measured energies in descending order of magnitude, and selecting a predetermined number of the strongest measured energies as containing signal components, the remaining energies relating to positions in which there are no signal components.
6. A method according to any one of claims 2 to 5, wherein the channel estimate window is a fixed width window.
7. A method according to any one of claims 2 to 5, wherein the channel estimate window is amplitude dependent.
8. A method according to claim 6, further comprising the step of measuring the ratio of signal response to inter cell interference plus receiver noise to exclude signal positions from measurement.
9. A method according to claim 7 or 8, further comprising the step of determining the relative amplitudes of adjacent pairs of peak responses as indications of related responses below the threshold.
10. A method according to any one of the preceding claims, wherein step b) comprises adding together path powers for all midamble codes other than that for a wanted signal.

11. A method according to any one of claims 1 to 9, wherein step b) comprises measuring the total received midamble code power over the period of the midamble code.
12. A method according to any one of the preceding claims, wherein step c) comprises weighting the inter cell interference plus noise by unity.
13. A method according to claim 12, wherein step c) further comprises weighting the intra cell interference by a value in the range of 0.03 to 0.003.
14. A method of minimising interference in the presence of one or more simultaneous co-channel intra cell signals in a mobile telecommunications system comprising a plurality of cells, each cell having a base station and a plurality of mobile stations associated therewith, substantially as hereinbefore described with reference to the accompanying drawing.



INVESTOR IN PEOPLE

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Claims searched: 1-14

Examiner: John Betts
Date of search: 4 August 2000

Patents Act 1977 Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:
UK CI (Ed.R): H4L (LDH)
Int CI (Ed.7): H04B 7/005 H04Q 7/32
Other: On-line: WPI, EPODOC, JAPIO, INSPEC, ELSEVIER

Documents considered to be relevant:

| Category | Identity of document and relevant passage | Relevant to claims |
|----------|---|--------------------|
| A | EP0762668 A (NOKIA) | |

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